CORRELATION OF THE RAISED BEACHES ON THE WEST SIDE OF LAKE MICHIGAN[1]

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CONTENTS

INTRODUCTION

The eastern border of Wisconsin, along the western shore of Lake Michigan and around Green Bay, has long been known to bear the marks of a series of stages of the extinct glacial Great Lakes. Terraces, bluffs, and beach ridges at various altitudes above the present lake were briefly described in 1877 by Dr. T. C. Chamberlin, in his report on the *Geology of Wisconsin.*[2] In the summer of 1893 Mr. F. B. Taylor touched at several points on the Wisconsin shore, in a rapid reconnaissance around the Great Lakes.[3] The highest shore-line discovered by him at Kewaunee, Green Bay, Sturgeon Bay, and northward through the Upper Peninsula of Michigan was found to rise toward the north at a rate of more than a foot per mile, as if due to regional deformation of the extinct water-plane. The Door County peninsula (north of Sturgeon Bay) was not visited; but the early measurements of Chamberlin in a general way confirmed this view. The "highest shore-line" was later identified by Taylor as the beach

[1] Published with the permisssion of the Director of the Wisconsin Geological and Natural History Survey.

[2] *Geology of Wisconsin,* Survey of 1873–77, Vol. II, pp. 219–28.

[3] "A Reconnaissance of the Ancient Shore Lines of Green Bay," *American Geologist,* Vol. XIII (1894), pp. 315-27; and other papers published in the *American Geologist* the same year.

of Lake Algonquin—a great lake which occupied the Huron, the Michigan, and part of the Superior basins, while the ice formed a dam across low passes to the northeast. In the absence of direct observation south of Kewaunee, the plane of this Algonquin beach was extended by inference so as to pass under the present lake near Two

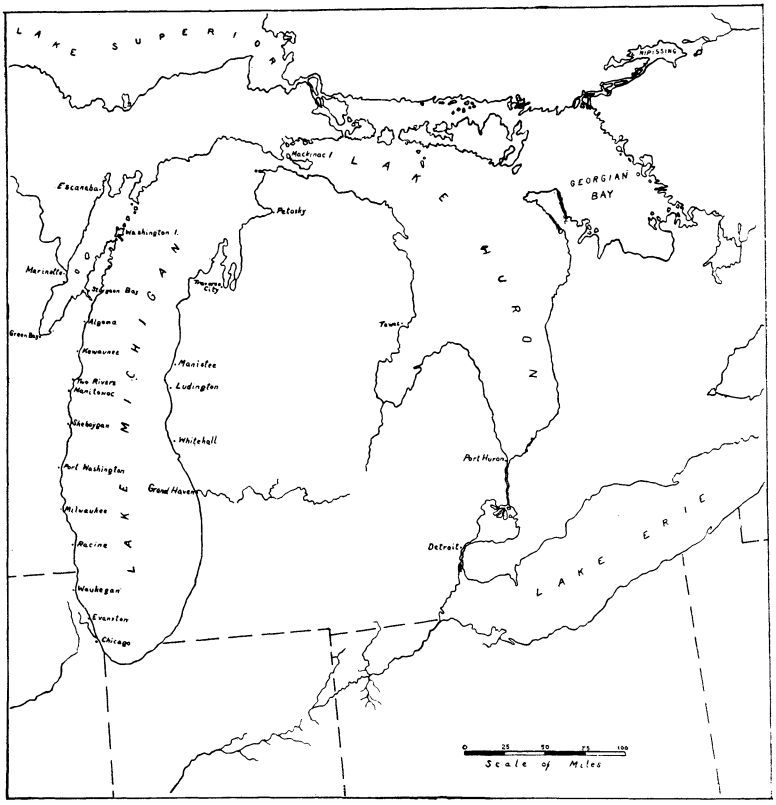


FIG. 1.—Map of part of the Great Lake region.

Rivers. Still later observations by Taylor and others, however, pointed to the probability that the shore-lines become horizontal above Lake Huron and Lake Michigan, encircling the southern ends of both.

In the southeastern part of the state and further south, around the head of Lake Michigan, a series of beaches, studied in detail by Mr. Frank Leverett, Dr. W. C. Alden, and others on the United States

Geological Survey,[1] were taken to mark a local ice-front lake, Lake Chicago. Of these beaches, the highest, about 60 feet above the lake, and a lower one about 40 feet, were not known to extend north of Racine County, Wisconsin, until very recently, when Alden found a terrace near Belgium (a few miles north of Port Washington) which corresponds somewhat closely to the 40-foot plane.

According to Taylor's studies, these beaches seemed to lie wholly above the plane of Lake Algonquin. Lower beaches of Lake Chicago, forming a complex group from 10 to 25 feet above Lake Michigan and called the "Toleston" beaches, had not been traced northward beyond Belgium when the present study was undertaken; and the actual relation between these and the inferred Algonquin plane was doubtful. It was suspected by Leverett, Chamberlin, and others that the lower beaches of the Toleston group (those from 10 to 15 feet above the lake) in the Chicago district might be shore-lines of Lake Algonquin.

In the summer of 1905 opportunity was given the writer by the Wisconsin Geological and Natural History Survey to study the old shore-lines of eastern Wisconsin with these problems of exploration and correlation in mind. Sufficient evidence was collected, it is thought, to show that only the beaches above 40 feet in the Chicago-Sheboygan district belong to a separate Lake Chicago; that the 20–25-foot Toleston beach of the Chicago district is the shore-line of Lake Algonquin; and that the strong 14-foot terraces and ridges of southeastern Wisconsin and northeastern Illinois mark the border of a later stage of importance, known as the stage of the Nipissing great lakes. It is the purpose of this paper to show on what grounds these conclusions were reached.

THE FIELD-WORK

The distance around the shores of Green Bay, from Marinette southward to Green Bay City, and thence northeastward to Washington and Rock Islands, is about 100 miles. From Washington Island southward along the shore of Lake Michigan to the Illinois line is approximately 200 miles. This entire stretch of shore, except

[1] See *Monograph XXXVIII*, U. S. Geological Survey, "The Illinois Glacial Lobe," by Leverett; and the Chicago Folio, No. 81, with discussion of Lake Chicago by Alden.

for about 20 miles near Milwaukee (part of the area recently covered by Alden), was traversed during the field season, chiefly on foot. Gasoline fishing-boats were used to advantage near the end of Door County Peninsula and on the southeastern shores of Green Bay. South of Sturgeon Bay the traverse was a continuous one, the present shore being followed wherever it has cut back a line of high cliffs beyond the earlier shore-lines, as is very common, and the fragments of abandoned shore-lines being followed from their beginnings, at the

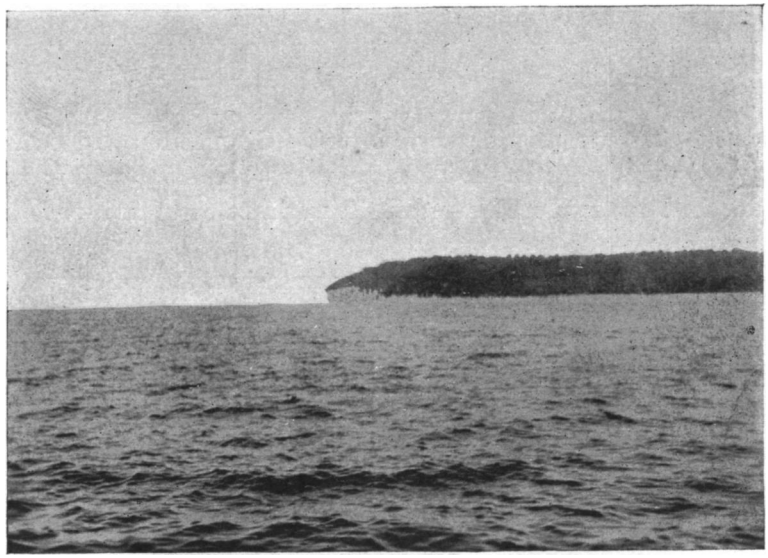


FIG. 2.—Boyer Bluff, at the northwestern end of Washington Island. Three steps or notches in the headland mark three important stages of Lake Algonquin.

lake cliffs, to their endings further along. North of Sturgeon Bay, on the less thickly settled peninsula, the beaches were not followed continuously, but were visited at short intervals of from one-half to five or six miles, wherever they are most accessible and best developed. Although the hand level was used in favorable places, to economize time, such measurements were not regarded as critical. With the spirit or "wye" level accurate profiles of the entire series of beaches were measured at about fifty localities, most of them on the Door County peninsula, where the best records were found. By this means it was possible to correlate the fragments with more than usual con-

fidence, and thus to reconstruct the water planes of the extinct lakes.

CHARACTER OF THE RECORD

On the rocky and exposed peninsula north of Sturgeon Bay the shore-lines are developed in conspicuous form. Fig. 2 shows a characteristic headland cut by the waves at successive levels so as to look like a great flight of steps. Heavy beach ridges of cobble stones occur across the bay heads or on shelving shores (see Fig. 3). The record of

FIG. 3.—Beach ridge of the Nipissing shore-line at Graceport, near Sturgeon Bay. It stands 19 feet above the level of Lake Michigan. On the left, between this beach and the shore of Green Bay, are lower ridges.

successive stages is singularly complete in this district, because exposure was great enough to allow each successive water-plane to be registered, while the rocky surface was usually too resistant to allow the shore cliffs of a lower lake stage to be cut back beyond higher shore-lines, and thus to destroy them.

South of Sturgeon Bay the expression of the beaches undergoes a marked change, corresponding to the change in the character of the ground. In place of bed-rock at the surface, there are thick red-clay deposits, in part ice-laid and in part water-laid, into which the waves

can cut with ease. Consequently the present shore south of Algoma commonly consists of high red-clay cliffs, which are rapidly retreating under the attack of the waves, and have long since eaten away the abandoned shore-lines of higher stages. When fragments are preserved, moreover, they commonly show that the lake at the Nipissing plane (the next important one above the plane of the present lake) cut back beyond the earlier shore-lines of Lake Algonquin and Lake Chicago. The record south of Sturgeon Bay, then, is relatively

FIG. 4.—Terrace and bluff of Lake Algonquin near Sturgeon Bay, 40 feet above Lake Michigan.

incomplete, and fragments of the lower stages are more common than those of the higher.

The same is true of the southeastern border of Green Bay. Along the low western shore of Green Bay, on the other hand, deposition of beach ridges has been the rule from the first, so that no cliff recession at the lower stages has here destroyed the record of earlier stages. There is an almost complete series of sandy ridges. But the weakness of expression of these beaches, probably in large measure an original weakness, together with the sandy structure which has per-

mitted the wind to spread and otherwise modify them, makes it somewhat difficult to find enough data for accurate measurements. Nevertheless, enough was found to show that the shore-lines on both sides of Green Bay correspond exactly to those on the Lake Michigan border.

THE ALGONQUIN SHORE-LINES

The systematic variation in altitude of the highest shore-line of Lake Algonquin can be seen by reference to the map. Here the figures mark the altitude of the Algonquin beach or terrace at each locality where it was measured with the spirit level. It is found by experimentation that these points lie closely in harmony with a tilted (or more accurately a warped) plane, on which the direction of steepest ascent is about N. 15° E., and that of no differential uplift is about N. 75° W. On Washington Island the highest Algonquin beach is about 90 feet above Lake Michigan. When followed southward, it is found to decline rather steadily until it is only 40 feet above the lake at Sturgeon Bay (Fig. 4). Throughout this distance it is marked either by a strongly cut terrace or by a well-built ridge of gravel or chip stone. Above it there are no signs of submergence. Below it several other shore-lines can be traced with equal distinctness. They have similar warped attitudes, and represent successive later planes of the lake, determined by repeated uplifts in its northern part.

In Fig. 5 the warped planes are drawn in profile in the direction of steepest inclination, N. 15° E. Each ordinate records a spirit-level measurement of the crest of a beach ridge or the base of a cut bluff, according to symbols which are explained in the legend. The vertical scale is 500 times the horizontal, greatly exaggerating the slope of the planes, and proportionately magnifying the discordance of the ordinates. In view of this, and of the chance of discordance due to (*a*) original variation in crest-line of the beaches and terraces, (*b*) the error involved in determining the datum lake-level during days when waves were running high, and (*c*) the error in leveling, which probably amounts to a fraction of a foot, the accordance of ordinates to the inferred planes of the highest Algonquin beach is remarkable. Nearly all the ordinates lie within 3 feet of the plane; and the few which are 5 or 6 feet too high are all of them points which were regarded at the time of their discovery as ridges built up to exceptional height

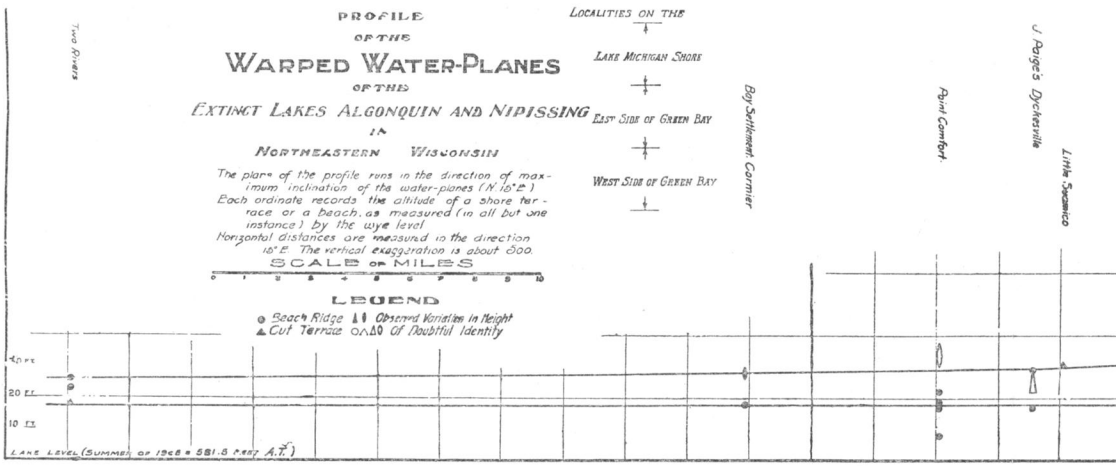
by storm-waves in places of unusual exposure. A great barrier ridge at Egg Harbor, for instance, which was built in 60 feet of water across the head of a bay, has a crest 7 feet higher than the cut terrace from which it tails out. The terrace corresponds closely to the inferred Algonquin plane; and a distant beach ridge lies at the same level just below the top of the barrier embankment. The discordance of this ordinate, like the two or three others, is wholly within expectation.

It is seen that this reconstructed plane slants southward from Washington Island at about 1½ feet per mile to Sturgeon Bay (slightly more in the northern part and less in the southern part), and that it suddenly becomes flatter near Sturgeon Bay and slants southward at the rate of about 8 inches per mile to Two Rivers, where it is nearly, if not quite, horizontal. For long distances south of Sturgeon Bay the Algonquin shore-line has been cut away during later stages; but the extinct flood-plains, now terraces, are found at appropriate heights in most of the stream valleys.

Two lower Algonquin planes, marked on Washington Island and near Death's Door by deeply cut terraces, can be traced southward in a similar way, converging slightly in that direction until at Sturgeon Bay they are so close together as to be difficult to identify separately. Ordinates which lie between the planes and mark weaker beaches suggest short-lived stages of intermediate age. In only one case (plane A′) has an attempt been made to reconstruct these less distinct planes.

THE NIPISSING AND LOWER SHORE-LINES

Below the slanting and diverging Algonquins is a nearly horizontal plane which is marked everywhere, and more strongly than any other (see Fig. 3). From 22 feet above the lake at Washington Island this declines almost imperceptibly to about 16–18 feet at Two Rivers—a drop of only 4 or 6 feet in a distance of about 90 miles. The remarkable strength of this shore-line—usually a high-cut bluff and broad terrace—together with its correspondence in altitude with the Nipissing shore-line traced by Taylor in the northern part of the Great Lake region down to Gladstone and Escanaba (just north of the eastern Wisconsin district), leaves little doubt that it marks the Nipissing plane, a stage of the lakes when both the North Bay outlet and


PROFILE
OF THE
WARPED WATER-PLANES
OF THE
EXTINCT LAKES ALGONQUIN AND NIPISSING
IN
NORTHEASTERN WISCONSIN
The plane of the profile runs in the direction of maximum inclination of the water-planes (N. 15° E.)
Each ordinate records the altitude of a shore terrace or a beach, as measured (in all but one instance) by the wye level.
Horizontal distances are measured in the direction 15° E. The vertical exaggeration is about 500.
SCALE OF MILES
0 1 2 3 4 5 6 7 8 9 10
LEGEND
Beach Ridge
Cut Terrace
Observed Variation in Height
Of Doubtful Identity
LOCALITIES ON THE
LAKE MICHIGAN SHORE
EAST SIDE OF GREEN BAY
WEST SIDE OF GREEN BAY
Two Rivers
Bay Settlement Cormier
Point Comfort
J. Paige's Dyckesville
Little Suamico
40 FT.
20 FT.
10 FT.
LAKE LEVEL (SUMMER OF 1908 = 581.8 FEET A.T.)

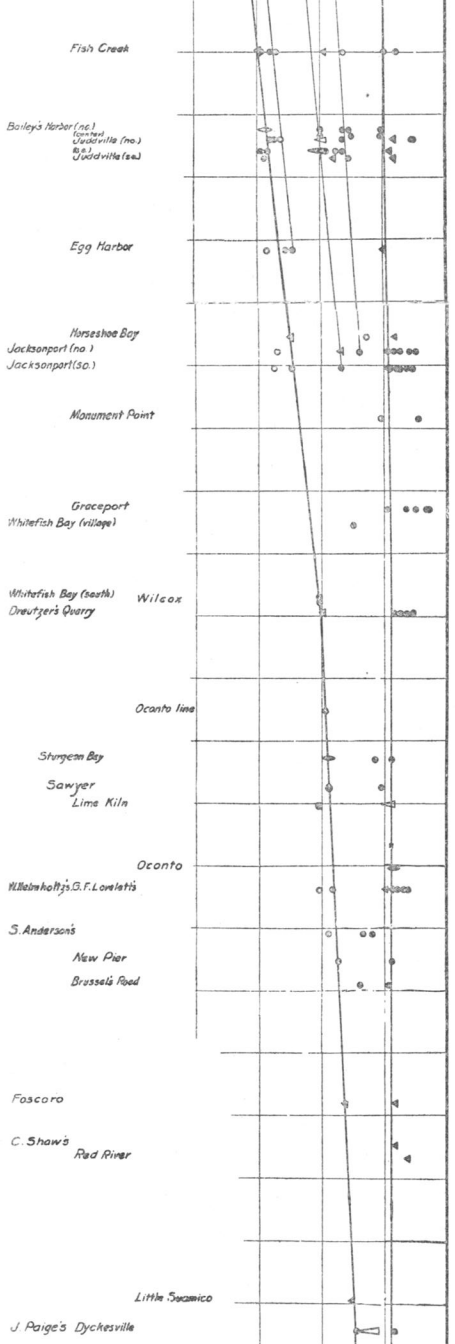
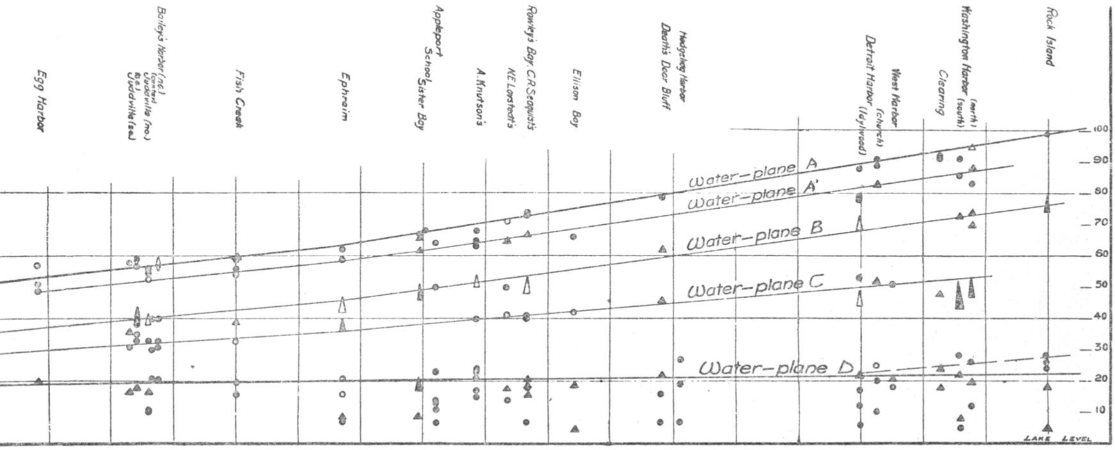


FIG. 5.—Profile of the warped water-planes.


Egg Harbor
Bailey's Harbor
Jacksonport
Fish Creek
Ephraim
Appleport
School
Sister Bay
A. Knutson's
Rowley's Bay
N.E. Lorsthoft's
Ellison Bay
Hedgehog Harbor
Death's Door Bluff
Detroit Harbor
West Harbor
Cleaning
Washington Harbor (north) (south)
Rock Island
Water-plane A
Water-plane A'
Water-plane B
Water-plane C
Water-plane D
100
90
80
70
60
50
40
30
20
10
LAKE LEVEL

the Port Huron outlet were running. The nearly horizontal position of this plane in eastern Wisconsin indicates clearly that very little deformation has occurred there since Nipissing time.

Below the Nipissing plane are usually several shore-lines which mark more recent stages of the lake, depending upon the deepening and widening of the present outlet. No attempt has been made to reconstruct them; but a 12-foot stage and a 9-foot stage are commonly recorded. These sometimes give rise to confusion regarding the altitude of the real Nipissing plane. Near Algoma, for instance, a very strong red-clay bluff of the Nipissing stage has at its base a terrace which is sometimes 12 and sometimes only 9 feet above Lake Michigan, but usually about 20, showing that the lake, after dropping a few feet below the 20-foot Nipissing level, easily cut back across the broad terrace to the base of the high Nipissing bluff.

EXTENSION OF THE ALGONQUIN AND NIPISSING PLANES SOUTH OF TWO RIVERS

Some difficulty attends the reconstruction of the old water-planes south of Two Rivers, for extensive cliff recession at the Nipissing and the present level has largely obliterated the record. (See Fig. 6.) No trace of a 25-foot beach ridge is seen between Two Rivers and Kenosha. High clay bluffs rise abruptly from the lake to heights above the extinct Algonquin plane, except where for short distances (as at Centerville, between Sheboygan and Port Washington, and at Fox Point) a terrace and bluff of the Nipissing stage has cut farther back into the upland. In most of the stream valleys along this distance there are terraces which mark the adjustment of streams to two and sometimes more high stages of the lake, their heights corresponding closely to the Algonquin and Nipissing planes. At Kenosha there are short remnants of a 25-foot beach ridge, and at Evanston, Ill., a strong beach ridge of the "Toleston" group of beaches of Lake Chicago runs inland at the height of 24 feet, and may be followed with occasional interruption through the Chicago district and around the head of Lake Michigan.

The flattening of the highest Algonquin plane in eastern Wisconsin, going southward toward Two Rivers, strongly suggests that it there becomes essentially horizontal. The presence of a very definite beach

ridge at the 25-foot level at those places where no cliff recession has occurred at a lower stage—viz., at Kenosha and in the Chicago district—agrees with this view. The abundance of shells in the "Toleston" beach, noted by Dr. Marcy before 1867,[1] and confirmed by other collectors since that time (including a recent discovery by the present writer in Evanston, Ill.), when contrasted with the absence of life in the 40- and 60-foot beaches, favors the idea that the Toleston or 25-foot beach marks a lake of less frigid water than the glacial Lake

FIG. 6.—Terrace and bluff of the Nipissing shore-line north of Algoma, Wis. In the foreground the old shore-line is cut away by the receding cliffs of the present lake. In the distance the Nipissing terrace is covered with a veneer of wind-drifted sand.

Chicago. Similar shells have been found in the Algonquin beaches on the west side of Lake Huron, by those working in Michigan. But of still greater significance is the fact that Mr. F. B. Taylor, Dr. A. C. Lane, and others in Michigan have found the Algonquin beach in a horizontal position in the southern part of the Lake Huron basin, 25 feet above the lake.[2] If there has been no tilting in the Huron basin

[1] See *Geological Survey of Illinois*, Part III, "Geology and Paleontology," p. 250 (1868).

[2] See *Geological Survey of Michigan, Report on Huron County*, by A. C. Lane, Vol. VII, Part II, p. 75.

south of Port Austin, as is inferred, it is probable that the same is true of the southern half of the Michigan basin, and the Algonquin beach should there be horizontal at the same altitude, 25 feet—the actual position of the highest member of the Toleston group.

The Nipissing plane can be extended in a similar way and on the basis of somewhat stronger evidence. In the region south of Sturgeon Bay the Nipissing bluffs are developed with remarkable strength, usually 30 and sometimes 80 feet high. The terrace shows an approximately horizontal attitude, descending southward at a very small fraction of a foot per mile, so that at Centerville it stands 14 feet above the lake. South of Centerville, measurements on the Nipissing terrace at Oostburg (near Sheboygan) south of Belgium, at the state line, at Zion City and Beach Station, Ill., place it within a foot or two of 14 feet. It forms a conspicuous bluff which lies just west of the tracks of the Chicago & Northwestern Railway between the state line and Waukegan, Ill. In the Chicago district, where no terraces were cut during the lower stages, an extensive series of beach ridges from 10 to 15 feet above Lake Michigan seem to mark the Nipissing and lower planes. Occasionally there is a strong wave-cut bluff, however, in the Chicago district at the 14-foot level, as at Englewood, where the low terrace is the strongest member of the "Toleston" series.

The exceptional strength of the Nipissing shore-line and the prevalence of sharply cut bluffs seem to express the gradual rising of the waters which is known to have led up to this stage in the lake history, according to the studies of Taylor and others. The evidence from Wisconsin and Illinois, therefore, seems to make the Nipissing shore-line horizontal at the altitude of about 14 feet in the southern part of Lake Michigan. Confirming this view is the evidence collected by Lane in Huron County, Mich., where a strong beach that stands 11 to 14 feet above Lake Huron is thought to mark the Nipissing plane.[1] A single observation recently made by Mr. Leverett and the present writer a few miles north of Port Huron places a strong beach, probably the Nipissing, at a height of 12 to 14 feet above the lake. Although previous observations in Michigan have suggested a slightly lower level for the Nipissing plane, it seems likely, all things con-

[1] *Op. cit.*, p. 76, and personally communicated to the writer.

sidered, that there has been the same confusion of terraces mentioned in connection with the strong bluffs near Algoma, Wis.—the upper few feet of the Nipissing terrace in many places having been stripped away at a slightly lower stage. The Nipissing plane, then, seems to be horizontal, and about 14 feet above the present lake-level in the southern parts of both the Huron and the Michigan basins.

THE LAKE CHICAGO SHORE-LINES

The terrace of the Calumet or 40-foot shore-line of Lake Chicago, traced by Alden near Belgium, Wis., was followed with some difficulty almost to Sheboygan. For most of this distance it is ill-defined, occasionally giving way to low bars; and its height seems in places to reach 49 feet. With a mile of the northern border of the Port Washington sheet, and again east of Oostburg, a gravel ridge was found 63 feet above the lake. If these fragments mark the Glenwood or 60-foot stage of Lake Chicago, they are important in extending that stage northward nearly to Sheboygan, where broad flats of stratified sand stand 60 feet above the lake. The Belgium and Oostburg 63-foot beach fragments are also important in showing that the Glenwood level persisted after a certain re-advance of the Michigan ice-lobe, which seems to have buried Glenwood beach gravels beneath a deposit of red clays near Milwaukee.[1] The fact that both the 60- and 40-foot beaches appear interruptedly nearly as far as Sheboygan, and there seem to end near a belt of rather strong morainic topography, when seen in the light of Taylor and Leverett's studies on the eastern side of the lake, suggests a re-advance of the ice in the vicinity of Manitowoc and Manistee, Mich., at the close of the 40-foot stage, overrunning for an unknown distance the northern part of the 60- and 40-foot beaches and destroying them. Further study of the beaches and moraines on both sides of Lake Michigan should make this point clear. So far as measurements were obtained on these Lake Chicago beaches, they seem to indicate a horizontal attitude, at least as far as Racine. It is possible that they rise a few feet between Racine and Oostburg.

[1] "The Delavan Lobe of the Lake Michigan Glacier," etc., U. S. Geological Survey, *Professional Paper No. 34*, by W. C. Alden, p. 69 (1904).

CONCLUSIONS

A detailed investigation of the terraces and raised beaches in eastern Wisconsin, with many measurements by spirit level, leads to the following conclusions.

1. There is a series of warped water-planes of Lake Algonquin, which rise at a moderate rate north of Sturgeon Bay, diverging, fan-fashion, until the highest is 90–95 feet above Lake Michigan at Washington Island. The divergence of these planes is interpreted to mean earth-movements contemporaneous with the Lake Algonquin stages. The tiltings seem to have decreased greatly in measure south of Sturgeon Bay, dying out in the vicinity of Two Rivers, where the Algonquin beach stands about 26 feet above the lake. South of that point the Algonquin shore-line is thought to be horizontal above Lake Michigan and represented by the highest beach of the "Toleston" group in the Chicago district, at a height of 20–25 feet, just as in the southern part of Lake Huron basin the Algonquin seems to be horizontal at a 25-foot level.

2. A shore-line of remarkable strength, usually marked by high-cut bluffs and terraces, which lies everywhere below the Algonquin sand in a horizontal position along the whole Wisconsin shore, is regarded as the Nipissing shore-line. At Washington Island this terrace is 20–22 feet above the lake; but it gradually declines to 18–20 feet at Sturgeon Bay and 16–18 feet at Two Rivers, reaching 14 feet at Centerville, at which level it seems to become horizontal and to be represented by strong 14-foot terraces in Sheboygan county, near the Illinois state line, and in the Chicago district.

3. The Glenwood or 60-foot and the Calumet or 40-foot beaches of Lake Chicago are poorly preserved north of Racine, but seem to run to Sheboygan, possibly being obliterated north of Manitowoc by an advance of the ice which formed the Manistee (Mich.) moraine.

4. If this identification and correlation is correct, one of the outlets for Lake Algonquin was the Chicago outlet, the sill of which is 8 feet above Lake Michigan. The depth of water in the Chicago outlet would have been slight after the earliest stages of Lake Algonquin, however; so the outlet at Port Huron probably played a more important part.

5. It is inferred, from the apparently horizontal position of the Algonquin and Nipissing planes in the southern parts of both the Huron and Michigan basins, that no earth-movements have affected this region since the earliest Algonquin stage, and that, if any deformations are now in progress in these two lake basins, they are limited to the more northerly portions.